

Chapter 2

Altitude Physiology

Human beings are not physiologically equipped for high altitudes. To cope, we must rely on preventive measures and, in some cases, life-support equipment. Although Army aviation primarily involves rotary-wing aircraft flying at relatively low altitudes, aircrews may still encounter altitude-associated problems. These may cause hypoxia, hyperventilation, and trapped-gas and evolved-gas disorders. By understanding the characteristics of the atmosphere, aircrews are better prepared for the physiological changes that occur with increasing altitudes.

SECTION I – ATMOSPHERE

PHYSICAL CHARACTERISTICS OF THE ATMOSPHERE

2-1. The atmosphere is like an ocean of air that surrounds the surface of the Earth. It is a mixture of water and gases. The atmosphere extends from the surface of the Earth to about 1,200 miles in space. Gravity holds the atmosphere in place. The atmosphere exhibits few physical characteristics; however, it shields the inhabitants of the Earth from ultraviolet radiation and other hazards in space. Without the atmosphere, the Earth would be as barren as the moon.

STRUCTURE OF THE ATMOSPHERE

2-2. The atmosphere consists of several concentric layers, each displaying its own unique characteristics. Each layer is known as a sphere. Thermal variances within the atmosphere help define these spheres, offering aviation personnel an insight into atmospheric conditions within each area. Between each of the spheres is an imaginary boundary, known as a pause.

THE TROPOSPHERE

2-3. The troposphere extends from sea level to about 26,405 feet over the poles to nearly 52,810 feet above the equator. It is distinguished by a relatively uniform decrease in temperature and the presence of water vapor, along with extensive weather phenomena.

2-4. Temperature changes in the troposphere can be accurately predicted using a mean-temperature lapse rate of -1.98 degrees Celsius per 1,000 feet. Temperatures continue to decrease until the rising air mass achieves an altitude where temperature is in equilibrium with the surrounding atmosphere. Table 2-1 illustrates the mean lapse rate and the pressure decrease associated with ascending altitude.

Table 2-1. Standard Pressure and Temperature Values at 40 Degrees Latitude for Specific Altitudes

Altitude (feet)	Pressure (in/Hg)	Pressure (mm/Hg)	Pressure (psi)	Temperature (°C)	Temperature (°F)
Sea Level	29.92	760.0	14.69	15.0	59.0
10,000	20.58	522.6	10.11	-4.8	23.3
18,000	14.95	379.4	7.34	-20.7	-5.3
20,000	13.76	349.1	6.75	-24.6	-12.3
25,000	10.51	281.8	5.45	-34.5	-30.1
30,000	8.90	225.6	4.36	-44.4	-48.0
34,000	7.40	187.4	3.62	-52.4	-62.3
35,332	6.80	175.9	3.41	-55.0	-67.0
40,000	5.56	140.7	2.72	-55.0	-67.0
43,000	4.43	119.0	2.30	-55.0	-67.0
50,000	3.44	87.3	1.69	-55.0	-67.0

THE STRATOSPHERE

2-5. The stratosphere extends from the tropopause to about 158,430 feet (about 30 miles). The stratosphere can be subdivided based on thermal characteristics found in different regions. Although these regions differ thermally, the water-vapor content of both regions is virtually nonexistent.

2-6. The first subdivision of the stratosphere is termed the isothermal layer. In the isothermal layer, temperature is constant at -55 degrees Celsius (-67 degrees Fahrenheit). Turbulence, traditionally associated with the stratosphere, is attributed to the presence of fast-moving jet streams, both here and in the upper regions of the troposphere.

2-7. The second subdivision of the stratosphere is characterized by rising temperatures. This area is the ozonosphere. The ozonosphere serves as a double-sided barrier that absorbs harmful solar ultraviolet radiation while allowing solar heat to pass through unaffected. In addition, the ozonosphere reflects heat from rising air masses back toward the surface of the Earth, keeping the lower regions of the atmosphere warm, even at night during the absence of significant solar activity.

THE MESOSPHERE

2-8. The mesosphere extends from the stratopause to an altitude of 264,050 feet (50 miles). Temperatures decline from a high of -3 degrees Celsius at the stratopause to nearly -113 degrees Celsius at the mesopause.

2-9. Noctilucent clouds are another characteristic of this atmospheric layer. Made of meteor dust/water vapor and shining only at night, these cloud formations are probably due to solar reflection.

THE THERMOSPHERE

2-10. The thermosphere extends from 264,050 feet (50 miles) to about 435 miles above the Earth. The uppermost atmospheric region, the thermosphere

is generally characterized by increasing temperatures; however, the temperature increase is in direct relation to solar activity. Temperatures in the thermosphere can range from -113 degrees Celsius at the mesopause to $1,500$ degrees Celsius during periods of extreme solar activity.

2-11. Another characteristic of the thermosphere is the presence of charged ionic particles. These particles are the result of high-speed subatomic particles emanating from the sun. These particles collide with gas atoms in the atmosphere and split them apart, resulting in a large number of charged particles (ions).

COMPOSITION OF THE ATMOSPHERE

2-12. The atmosphere of the Earth is a mixture of gases. Although the atmosphere contains many gases, few are essential to human survival. Those gases required for human life are nitrogen, oxygen, and carbon dioxide. Table 2-2 indicates the percentage concentrations of gases commonly found in the atmosphere.

Table 2-2. Percentages of Atmospheric Gases

Gas	Symbol	Volume (%)
Nitrogen	N ₂	78.0840
Oxygen	O ₂	20.9480
Argon	A	0.9340
Carbon Dioxide	CO ₂	0.0314
Neon	Ne	0.0018
Helium	He	0.0005
Hydrogen	H ₂	<0.0001

NITROGEN

2-13. The atmosphere of the Earth consists mainly of nitrogen. Although a vital ingredient in the chain of life, nitrogen is not readily used by the human body. However, nitrogen saturates body fluids and tissues as a result of respiration. Aircrews must be aware of possible evolved-gas disorders because of the decreased solubility of nitrogen at higher altitudes.

OXYGEN

2-14. Oxygen is the second most plentiful gas in the atmosphere. The process of respiration unites oxygen and sugars to meet the energy requirements of the body. The lack of oxygen in the body at altitude will cause drastic physiological changes that can result in death. Therefore, oxygen is of great importance to aircrew members.

CARBON DIOXIDE

2-15. Carbon dioxide is the product of cellular respiration in most life forms. Although not present in large amounts, the CO₂ in the atmosphere plays a vital role in maintaining the oxygen supply of the Earth. Through photosynthesis, plant life uses CO₂ to create energy and releases O₂ as a

by-product. As a result of animal metabolism and photosynthesis, CO_2 and O_2 supplies in the atmosphere remain constant.

OTHER GASES

2-16. Other gases—such as argon, xenon, and helium—are present in trace amounts in the atmosphere. They are not as critical to human survival as are nitrogen, oxygen, and carbon dioxide.

ATMOSPHERIC PRESSURE

2-17. Standard atmospheric pressure, or barometric pressure, is the force (that is, weight) exerted by the atmosphere at any given point. An observable characteristic, atmospheric pressure can be expressed in different forms, depending on the method of measurement. Atmospheric pressure decreases with increasing altitude, making barometric pressure of great concern to airmen because oxygen diffusion in the body depends on total barometric pressure. Figure 2-1 illustrates the standard atmospheric pressure measurements at 59 degrees Fahrenheit (15 degrees Celsius) at sea level.

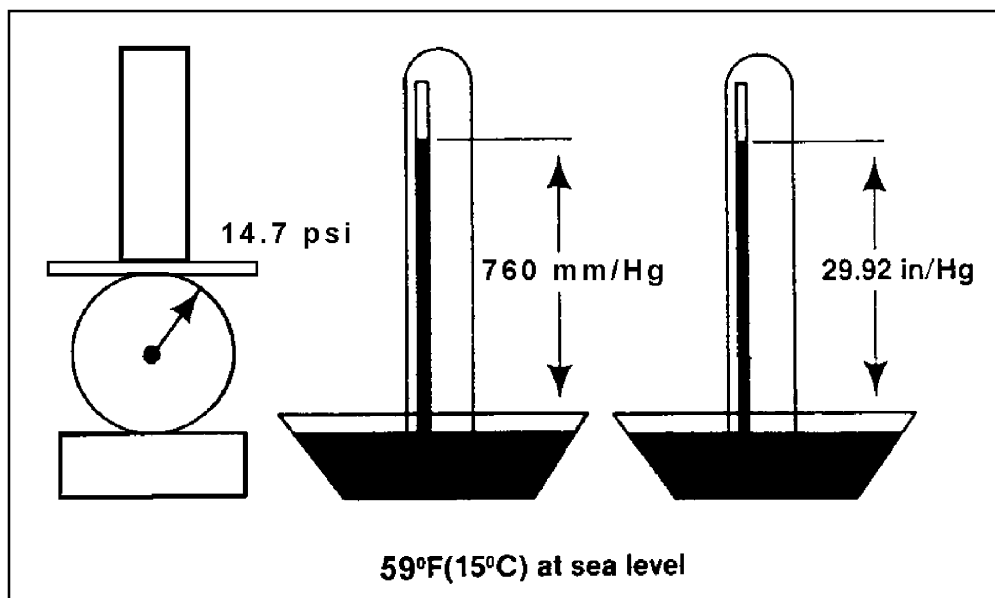


Figure 2-1. Standard Atmospheric Pressure Measurements at 59 Degrees Fahrenheit (15 Degrees Celsius) at Sea Level

DALTON'S LAW OF PARTIAL PRESSURES

2-18. A close relationship exists between atmospheric pressure and the amount of the various gases in the atmosphere. This relationship is referred to as Dalton's Law of Partial Pressures. Dalton's Law states that the pressure exerted by a mixture of ideal (nonreacting) gases is equal to the sum of the pressures that each gas would exert if it alone occupied the space filled by the mixture. The pressure of each gas within a gaseous mixture is independent of the pressures of the other gases in the mixture. The independent pressure of

each gas is termed the partial pressure of that gas. Figure 2-2 represents the concept of Dalton's Law as related to the atmosphere of the Earth. Mathematically, Dalton's Law can be expressed as follows:

$$P_t = P_N + P_{O_2} + P_{CO_2} + \dots \text{ (constant volume and temperature)}$$

Where P_t represents the total pressure of the mixture, P_N , P_{O_2} , P_{CO_2} , ... represent the partial pressures of each individual gas, V represents volume, and T represents temperature. To determine the partial pressure of the gases in the atmosphere (or any gaseous mixture whose concentrations are known), the following mathematical formula can be used:

Percentage of atmospheric

concentration

of the individual gas

100

Total atmospheric

pressure at a given altitude =

Partial pressure of the individual gas

2-19. Dalton's Law states that the pressure exerted by a mixture of ideal (nonreacting) gases is equal to the sum of the pressures that each gas would exert if it alone occupied the space filled by the mixture. The pressure of each gas within a gaseous mixture is independent of the pressures of the other gases in the mixture. The independent pressure of each gas is termed the partial pressure of that gas. Figure 2-2 represents the concept of Dalton's Law as related to the atmosphere of the Earth.

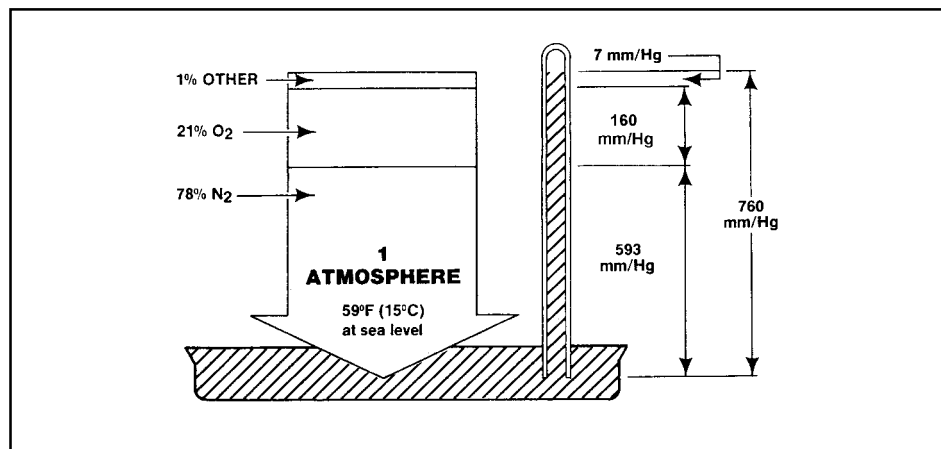


Figure 2-2. Dalton's Law of Partial Pressures as Related to the Atmosphere of the Earth

2-20. For the aircrew member, Dalton's law illustrates that increasing altitude results in a proportional decrease of partial pressures of gases found in the atmosphere. Although the percentage concentration of gases remains stable with increasing altitude, each partial pressure decreases in direct proportion to the total barometric pressure. Table 2-3 shows the relationship between barometric pressure and partial pressure.

Table 2-3. Partial Pressures of O₂ at Various Altitudes

Altitude (feet)	Atmospheric Pressure (mm/Hg)	PAO₂ (mm/Hg)	PVO₂ (mm/Hg)	Pressure Differential (mm/Hg)	Blood Saturation (%)
Sea Level	760	100	40	60	98
10,000	523	60	31	29	87
18,000	380	38	26	12	72
22,000	321	30	22	8	60
25,000	282	7	4	3	9
35,000	179	0	0	0	0

2-21. Changes in the partial pressure of oxygen dramatically affect respiratory functions within the human body. Any decrease in the partial pressure of oxygen quickly results in physiological impairment. Although this impairment may not be noticed initially at lower altitudes, the effects are cumulative and grow progressively worse as altitude increases.

2-22. Decreases in the partial pressure of nitrogen, especially at high altitude, can lead to a decrease in the solubility of N₂ in the body. This decrease in N₂ solubility can result in decompression sickness.

PHYSIOLOGICAL ZONES OF THE ATMOSPHERE

2-23. Humans are unable to adapt physiologically to all of the physical changes that occur in the different regions of the atmosphere. Because man evolved on the surface, humans are especially susceptible to the dramatic temperature and pressure changes that take place during ascent and sustained aerial flight. Because of these factors, the atmosphere can be further divided (by altitude) into three distinct physiological zones. These divisions are primarily based on pressure changes that occur within these parameters and the resultant effects on human physiology.

THE EFFICIENT ZONE

2-24. Extending upward from sea level to 10,000 feet, the efficient zone provides aircrews with a near-ideal physiological environment. Although the barometric pressure drops from 760 mm/Hg at sea level to 523 mm/Hg at 10,000 feet, Po₂ (partial pressure of oxygen) levels within this range allow humans to operate in the efficient zone without using protective equipment; however, sustained flight in the upper portions of this area may require acclimatization. Some minor problems associated with the efficient zone are ear and sinus blocks and gas expansion in the digestive tract. Also, without the use of supplemental oxygen, a decrease in night vision capabilities will occur above 4,000 feet.

THE DEFICIENT ZONE

2-25. The deficient zone of the atmosphere ranges from 10,000 feet at its base to 50,000 feet at its highest point. Because atmospheric pressure at 10,000

feet is only 523 mm/Hg, missions in the deficient zone carry a high degree of risk unless supplemental-oxygen/cabin-pressurization systems are used. As flights approach the upper limit of the deficient zone, decreasing barometric pressures (down to 87 mm/Hg) make trapped-gas disorders occur more frequently.

THE SPACE EQUIVALENT ZONE

2-26. Extending from 50,000 feet and continuing to the outer fringes of the atmosphere, the space equivalent zone is totally hostile to human life. Therefore, flight in the space equivalent zone requires a completely artificial atmospheric environment. Unprotected exposure to the extremely low temperatures and pressures found at these high altitudes can quickly result in death. An example of how dangerous this area can be is found at 63,000 feet (Armstrong's line). The barometric pressure at this altitude is only 47 mm/Hg, which equals the partial pressure of water in the body. At this pressure, water begins to "boil" within the body as it changes into a gaseous vapor.

SECTION II – CIRCULATORY SYSTEM

STRUCTURE AND FUNCTION OF THE CIRCULATORY SYSTEM

2-27. The circulatory system, shown in Figure 2-3, constitutes the physiologic framework required to transport blood throughout the body. A fundamental function of the circulatory system (along with the lymphatic system) is fluid transport. Other important functions of this system include meeting body cell nutrition and excretion demands, along with body-heat and electrochemical equilibrium requirements. Circulatory components include arteries, capillaries, and veins that stretch to nearly every cell in the body.

ARTERIES

2-28. Conducting blood away from the ventricles of the heart, the arteries are strong, elastic vessels that can withstand relatively high pressures. Arterial vessels generally carry oxygen-rich blood to the capillaries for use by the tissues.

CAPILLARIES

2-29. The body's smallest blood vessels, the capillaries, form the junction between the smallest arteries (arterioles) and the smallest veins (venules). Actually semipermeable extensions of the inner linings of the arterioles and venules, the capillaries provide body tissues with access to the bloodstream. Capillaries can be found virtually everywhere in the body, providing needed gas-/nutrient-exchange capabilities to nearly every body cell.

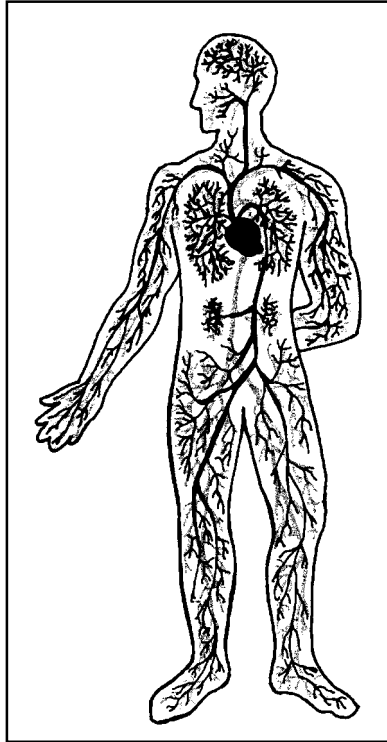


Figure 2-3. Structures of the Circulatory System

VEINS

2-30. Transporting blood from the capillaries back to the atria of the heart, the veins are the blood-return portion of the circulatory system. A low-pressure pathway, the veins also possess flap-like valves that ensure that blood flows only in the direction of the heart. In addition, the veins can constrict or dilate, based on the body's requirements. This unique ability allows blood flow and pressure to be modified, based on such factors as body heat or trauma.

COMPONENTS AND FUNCTIONS OF BLOOD

2-31. Although blood volume varies with body size, the average adult has a blood volume approaching 5 liters. About 5 percent of total body weight, blood is actually a form of connective tissue whose cells are suspended in a liquid intercellular material. The cellular portions of the blood compose about 45 percent of blood volume and consist mainly of red blood cells, white blood cells, and blood platelets. The remaining 55 percent of the blood is a liquid called plasma. Each of these components performs unique functions, summarized in Figure 2-4.

RED BLOOD CELLS

2-32. Most of the body's supply of oxygen is transported by the red blood cells (erythrocytes). Because oxygenation of red blood cells depends on the P_{O_2} in

the atmosphere, aircrews may begin to suffer from oxygen deficiency (hypoxia) even at low altitudes. RBC structure, appearance, and production are among the factors that are affected when erythrocytes experience hypoxia.

2-33. Hemoglobin makes up about one-third of every red blood cell. Composed of several polypeptide chains and iron-containing heme groups, hemoglobin attracts oxygen molecules through an electrochemical magnetic process. Just as opposing poles on a magnet attract, so does the iron content (Fe^{2+}) within hemoglobin attract oxygen (O_2^{2-}).

2-34. When the blood supply is fully saturated with oxygen, as in arterial blood, blood takes on a bright-red color as oxyhemoglobin is formed. As blood passes through the capillaries, it releases oxygen to the surrounding tissues. As a result, deoxyhemoglobin forms and gives venous blood a dark-red color.

2-35. Red blood cells are produced in the red bone marrow. The number of RBCs in circulating blood is relatively stable; however, environmental factors play a large role in determining the actual RBC count. Smoking, an inadequate diet, and the altitude where one lives all contribute to fluctuations in RBC count. In fact, people residing above 10,000 feet may have up to 30 percent more erythrocytes than those living at sea level.

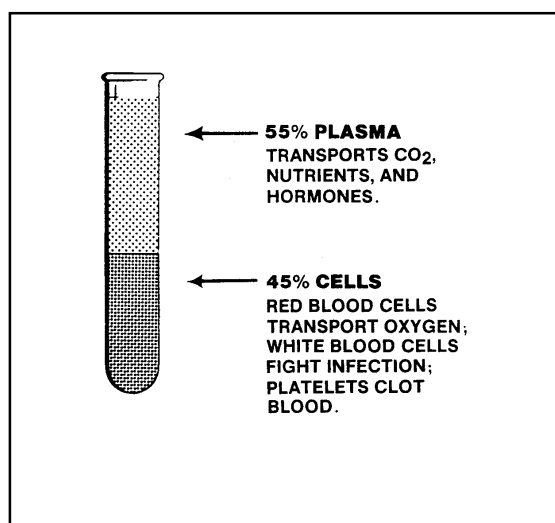


Figure 2-4. Functions of Blood Components

WHITE BLOOD CELLS

2-36. The principal role of the white blood cells, or leukocytes, is to fight/control various disease conditions, especially those caused by invading microorganisms. Although WBCs are typically larger than RBCs, WBCs can squeeze between the cells of blood vessels to reach diseased tissues. WBCs also help form natural immunities against numerous disease processes.

PLATELETS

2-37. Although not complete cells, the platelets, or thrombocytes, arise from small, fragmented portions of much larger cells produced in the red bone marrow. About half the size of an RBC, the platelets react to any breach in the circulatory system through initialization of blood coagulation and blood-vessel contraction.

PLASMA

2-38. The liquid portion of the blood is a translucent, straw-colored fluid, known as plasma. All of the cellular structures in the bloodstream are suspended in this liquid. Composed mainly of water, plasma also contains proteins and inorganic salts. Some of the important functions of the plasma are to transport nutrients, such as glucose, and waste products, such as carbon dioxide.

SECTION III – RESPIRATORY SYSTEM

THE PROCESSES OF BREATHING AND RESPIRATION

2-39. All known living organisms exchange gases with their environment. This gas exchange is known as respiration. The processes of respiration are breathing, external respiration, and internal respiration.

BREATHING

2-40. Breathing can be described as a spontaneous, rhythmic mechanical process. Contraction and relaxation of the respiratory muscles cause gases to move in and out of the lungs, thereby providing the body a gaseous media for exchange purposes.

EXTERNAL RESPIRATION

2-41. External respiration takes place in the alveoli of the lungs. Air, which includes oxygen, is moved to the alveoli by the mechanical process of breathing. Once in the alveolar sacs, oxygen diffuses from the incoming air into the bloodstream. At the same time, carbon dioxide diffuses from the venous blood into the alveolar sacs.

INTERNAL RESPIRATION

2-42. Internal respiration includes the use of blood oxygen and carbon dioxide production by tissue cells, as well as gas exchange between cells and the surrounding fluid medium. These mechanisms, known as the metabolic process, produce the energy needed for life.

FUNCTIONS OF RESPIRATION

2-43. Respiration has several functions. It brings O₂ into the body, removes CO₂ from the body, and helps maintain the temperature and the acid-base balance of the body.

OXYGEN INTAKE

2-44. The primary function of respiration is the intake of O_2 . Oxygen enters the body through the respiratory system and is transported within the body through the circulatory system. All body cells require oxygen to metabolize food material.

CARBON-DIOXIDE REMOVAL

2-45. Carbon dioxide is one of the by-products of the metabolic process. CO_2 dissolves in the blood plasma, which then transports it from the tissues to the lungs so that it can be released.

BODY-HEAT BALANCE

2-46. Body temperature is usually maintained within a narrow range (from 97 to 100 degrees Fahrenheit). Evaporation of bodily fluids (such as perspiration) is one method of heat loss that helps maintain body-heat balance. The warm, moist air released during exhalation also aids in this process.

BODY CHEMICAL BALANCE

2-47. A delicate balance exists between the amounts of oxygen and carbon dioxide in the body. The uptake of O_2 and CO_2 takes place through extensive chemical changes in the hemoglobin and plasma of the blood. Disrupting these chemical pathways changes the chemical balance of the body.

2-48. Under normal conditions, the measure of relative acidity or alkalinity (pH level) within the body is 7.35 to 7.45. During respiration, the partial pressure of carbon dioxide elevates, the acidity level increases, and the pH value lowers to less than 7.3. Conversely, too little CO_2 causes the blood to become more alkaline and the pH value to rise. Figure 2-5 shows how the amount of carbon dioxide in the body affects the pH level of the blood.

2-49. Because the human body maintains equilibrium within narrow limits, the respiratory centers of the brain sense any shift in the blood pH and partial pressure of CO_2 (P_{CO_2}) levels. When unusual levels occur, chemical receptors trigger the respiratory process to help return the P_{CO_2} and pH levels to normal limits. The 7.2 to 7.6 limits are critical for the necessary uptake of O_2 by the blood and the release of that O_2 to tissues.

PHASES OF EXTERNAL RESPIRATION

2-50. The respiratory cycle is an involuntary process that continues unless a conscious effort is made to control it. External respiration occurs in two phases: active (inhalation) and passive (exhalation). Figure 2-6 illustrates these phases.

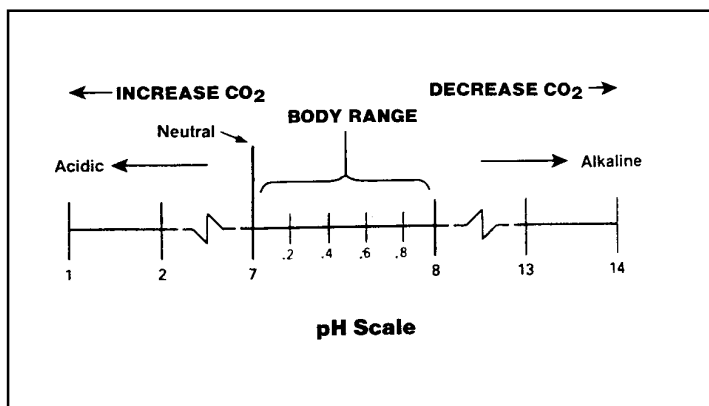


Figure 2-5. Relationship of CO₂ Content and pH Level of the Blood

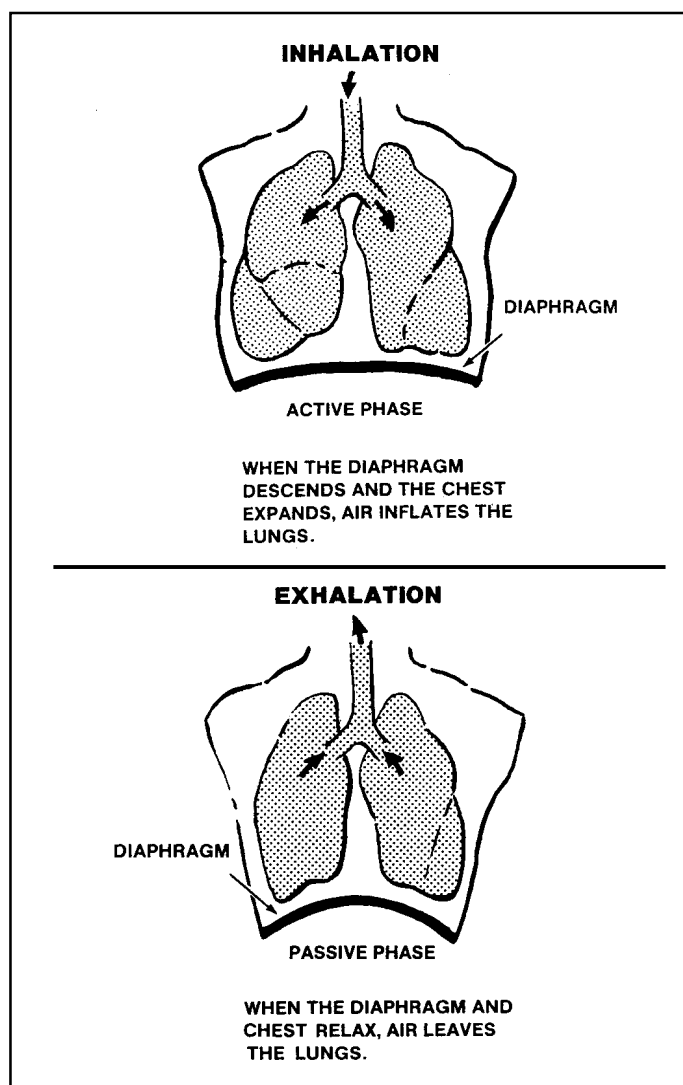


Figure 2-6. The Phases of Respiration

ACTIVE PHASE (INHALATION)

2-51. The movement of air into the lungs is the active phase of external respiration, or inhalation. It is caused by the expansion of the chest wall and downward motion of the diaphragm. Inhalation creates an area of low pressure because of the increased volume in the lungs. Because of the greater outside pressure, air will then rush into the lungs to inflate them.

PASSIVE PHASE (EXHALATION)

2-52. In the passive phase of external respiration, or exhalation, the diaphragm relaxes and the chest wall contracts downward to create increased pressure inside the lungs. Once the glottis opens, this pressure inside the lungs causes the air to rush out, which frees CO_2 to the atmosphere.

COMPONENTS OF THE RESPIRATORY SYSTEM

2-53. The respiratory system consists of passages and organs that bring atmospheric air into the body. The components of the respiratory system, shown in Figure 2-7, include the oral-nasal passage, pharynx, larynx, trachea, bronchi, bronchioles, alveolar ducts, and alveoli.

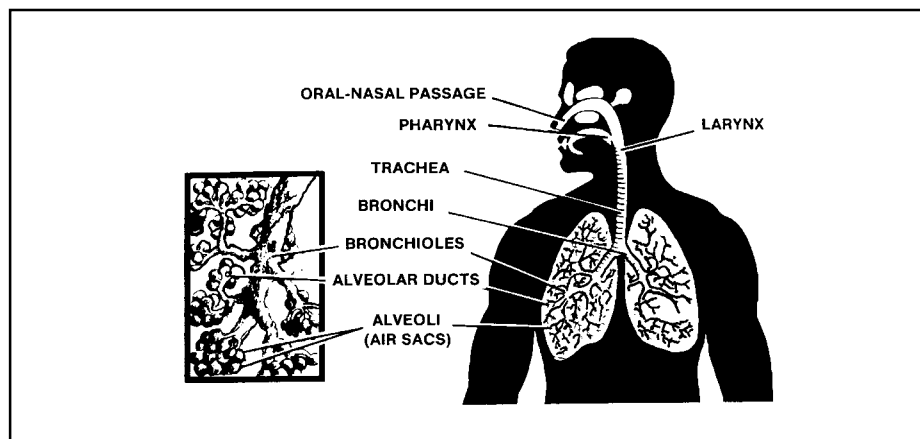


Figure 2-7. Components of the Respiratory System

ORAL-NASAL PASSAGE

2-54. The oral-nasal passage includes the mouth and nasal cavities. The nasal passages are lined with a mucous membrane that contains many fine, ciliated hair cells. The membrane's primary purpose is to filter air as it enters the nasal cavity. The hairs continually clean the membrane by sweeping filtered material to the back of the throat where it is either swallowed or expelled through the mouth. Therefore, air that enters through the nasal cavity is better filtered than air that enters through the mouth.

PHARYNX

2-55. The pharynx, the back of the throat, is connected to the nasal and oral cavities. It primarily humidifies and warms the air entering the respiratory system.

TRACHEA

2-56. The trachea, or windpipe, is a tube through which air moves down into the bronchi. From there, air continues to move down increasingly smaller passages, or ducts, until it reaches the small alveoli within the lung tissue.

ALVEOLI

2-57. Each tiny alveolus is surrounded by a network of capillaries that joins veins and arteries. The microscopic capillaries, each having a wall only one cell in thickness, are so narrow that red blood cells move through them in single file. The actual gaseous exchange between CO_2 and O_2 occurs in the alveoli.

2-58. Carbon dioxide and oxygen move in and out of alveoli because of the pressure differentials between their CO_2 and O_2 levels and those in surrounding capillaries. This movement is based on the law of gaseous diffusion: a gas always moves from an area of high pressure to an area of lower pressure. Figure 2-8 illustrates the exchange of CO_2 and O_2 between an alveolus and a capillary.

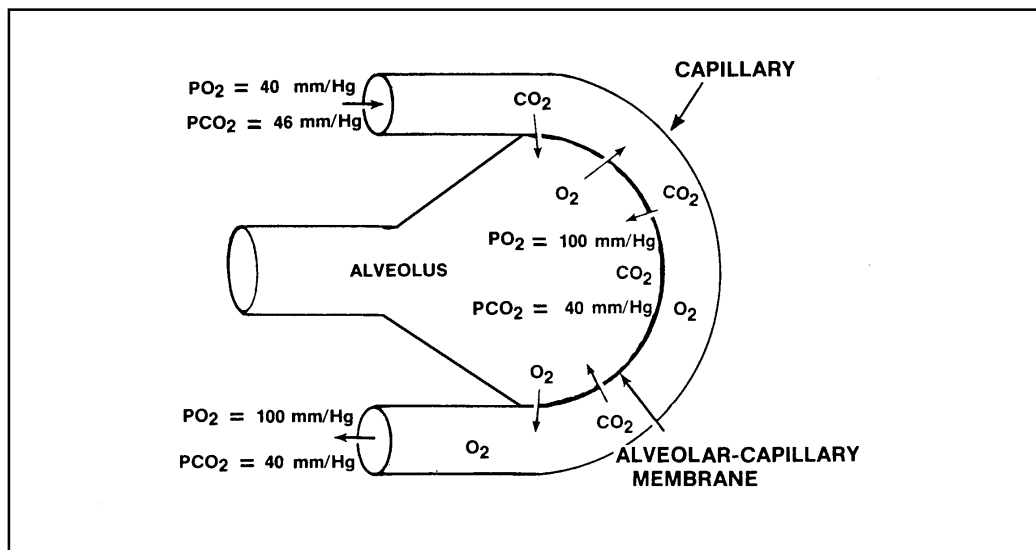


Figure 2-8. Diffusion of CO_2 and O_2 Between an Alveolus and a Capillary

2-59. When O_2 reaches the alveoli of the lungs, it crosses a thin cellular barrier and moves into the capillary bed to reach the oxygen-carrying RBCs. As the oxygen enters the alveoli, it has a partial pressure of oxygen of about 100 mm/Hg. Within the blood, the PO_2 of the venous return blood is about 40 mm/Hg. As the blood traverses the capillary networks of the alveoli, the O_2 flows from the area of high pressure within the alveoli to the area of low pressure within the blood. Thus, O_2 saturation takes place.

2-60. Carbon dioxide diffuses from the blood to the alveoli in the same manner. The partial pressure of carbon dioxide (Pco_2) in the venous return blood of the capillaries is about 46 mm/Hg, as compared to a Pco_2 of 40

mm/Hg in the alveoli. As the blood moves through the capillaries, the CO_2 moves from the high Pco_2 in the capillaries to an area of lower Pco_2 in the alveoli. The CO_2 is then exhaled during the next passive phase (exhalation) of respiration.

Note: The exchange of O_2 and CO_2 between tissue and capillaries occurs in the same manner as it does between the alveoli and capillaries. Figure 2-9 shows the exchange between tissue and a capillary.

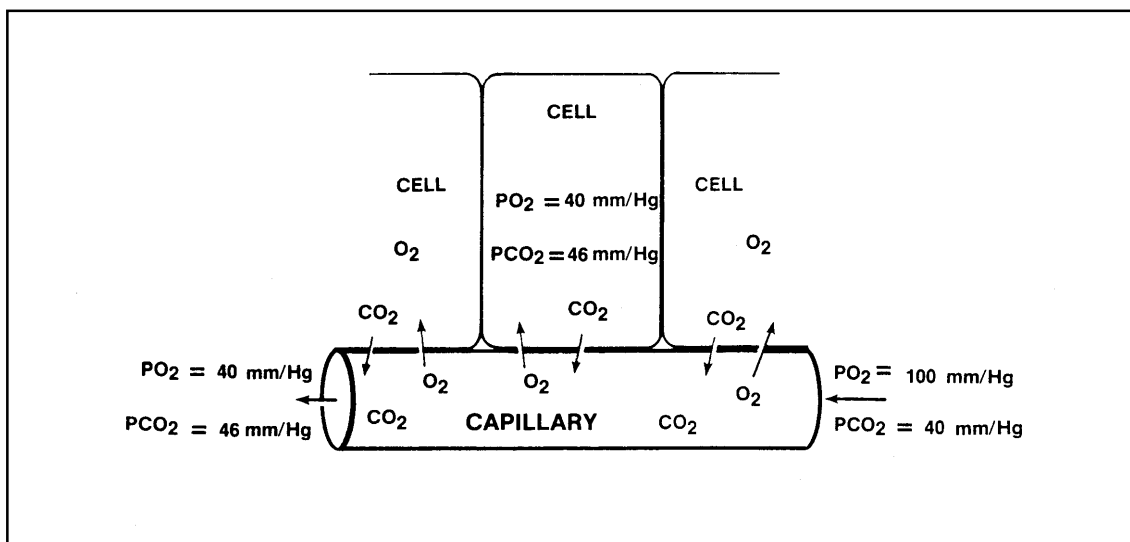


Figure 2-9. Diffusion of CO_2 and O_2 Between Tissue and a Capillary

2-61. The amount of O_2 and CO_2 transferred across the alveolar-capillary membrane into the blood depends primarily on the alveolar pressure of oxygen in relation to the venous pressure of oxygen. This pressure differential is critical to the crew member because O_2 saturation in the blood decreases as altitude increases. This decrease in O_2 saturation can lead to hypoxia, which is caused by a deficiency of O_2 in the body tissues. Table 2-4 shows the relationship between altitude and O_2 saturation.

Table 2-4. Correlation of Altitude and Blood O_2 Saturation

Altitude (feet)	Atmospheric Pressure (mm/Hg)	PAO_2 (mm/Hg)	PVO_2 (mm/Hg)	Pressure Differential (mm/Hg)	Blood Saturation (%)
Sea Level	760	100	40	60	98
10,000	523	60	31	29	87
18,000	380	38	26	12	72
22,000	321	30	22	8	60
25,000	282	7	4	3	9
35,000	179	0	0	0	0

SECTION IV – HYPOXIA

CHARACTERISTICS OF HYPOXIA

2-62. Hypoxia results when the body lacks oxygen. Hypoxia tends to be associated only with flights at high altitude. However, many other factors—such as alcohol abuse, heavy smoking, and various medications—interfere with the blood's ability to carry oxygen. These factors can either diminish the ability of the blood to absorb oxygen or reduce the body's tolerance to hypoxia.

TYPES OF HYPOXIA

2-63. There are four major types of hypoxia: hypoxic, hypemic, stagnant, and histotoxic. They are classified according to the cause of the hypoxia.

HYPOXIC HYPOXIA

2-64. Hypoxic hypoxia occurs when not enough oxygen is in the air or when decreasing atmospheric pressures prevent the diffusion of O_2 from the lungs to the bloodstream. Aviation personnel are most likely to encounter this type at altitude. It is due to the reduction of the PO_2 at high altitudes, as shown in Figure 2-10.

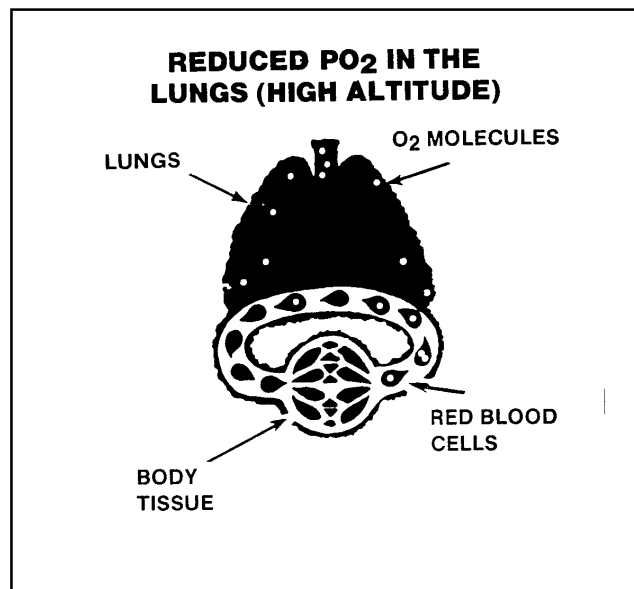


Figure 2-10. Hypoxic Hypoxia

HYPEMIC HYPOXIA

2-65. Hypemic, or anemic, hypoxia is caused by a reduction in the oxygen-carrying capacity of the blood, as shown in Figure 2-11. Anemia and blood loss are the most common causes of this type. Carbon monoxide, nitrites, and sulfa drugs also cause this hypoxia by forming compounds with hemoglobin and reducing the hemoglobin that is available to combine with oxygen.

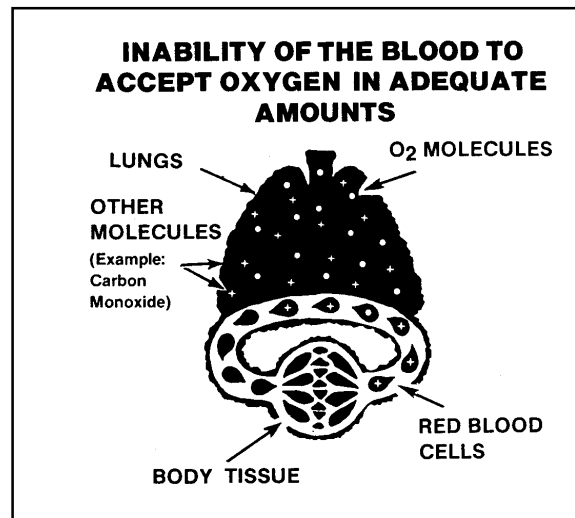


Figure 2-11. Hypemic Hypoxia

STAGNANT HYPOXIA

2-66. In stagnant hypoxia, the oxygen-carrying capacity of the blood is adequate but, as shown in Figure 2-12, circulation is inadequate. Such conditions as heart failure, arterial spasm, and occlusion of a blood vessel predispose the individual to stagnant hypoxia. More often, when a crew member experiences extreme gravitational forces, disrupting blood flow and causing the blood to stagnate.

HISTOTOXIC HYPOXIA

2-67. This type results when there is interference with the use of O₂ by body tissues. Alcohol, narcotics, and certain poisons—such as cyanide—interfere with the cells' ability to use an adequate supply of oxygen. Figure 2-13 shows the result of this oxygen deprivation.

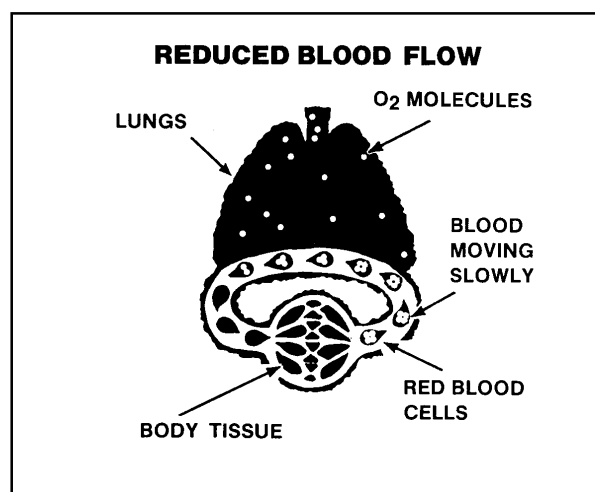


Figure 2-12. Stagnant Hypoxia

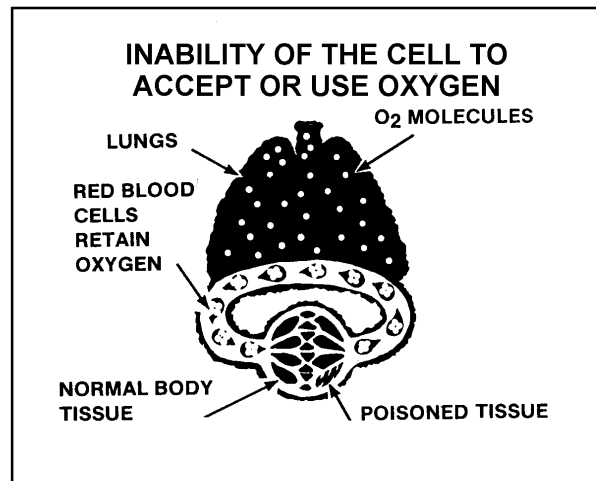


Figure 2-13. Histotoxic Hypoxia

SIGNS, SYMPTOMS, AND SUSCEPTIBILITY TO HYPOXIA

SIGNS AND SYMPTOMS OF HYPOXIA

2-68. Signs are observable by the other aircrew members and, therefore, are objective. Individual aircrew members observe or feel their own symptoms. These symptoms vary from one person to another and, therefore, are subjective.

2-69. Aviation personnel commonly experience mild hypoxia at altitudes at or above 10,000 feet. Those who fly must be able to recognize the possible signs and symptoms. Being able to recognize these signs and symptoms is particularly important because the onset of hypoxia is subtle and produces a false sense of well-being. Crew members are often engrossed in flight activities and do not readily notice the symptoms of hypoxia. Usually, however, most individuals experience two or three unmistakable symptoms or signs that cannot be overlooked. Figure 2-14 lists the signs and symptoms.

Symptoms (Subjective)	Signs (Objective)
Air Hunger	Hyperventilation
Apprehension	Cyanosis
Fatigue	Mental Confusion
Headache	Poor Judgment
Dizziness	Muscle Incoordination
Hot and Cold Flashes	
Euphoria	
Belligerence	
Blurred Vision	
Tunnel Vision	
Numbness	
Tingling	

➡ UNCONSCIOUSNESS ⬅

Figure 2-14. Possible Signs and Symptoms of Hypoxia

SUSCEPTIBILITY TO HYPOXIA

2-70. Individuals vary widely in their susceptibility to hypoxia. Several factors determine individual susceptibility.

Onset Time and Severity

2-71. The onset time and severity of hypoxia vary with the amount of oxygen deficiency. Crew members must be able to recognize hypoxia and immediately determine the cause.

Self-Imposed Stress

2-72. **Physiological Altitude.** An individual's physiological altitude, the altitude that the body feels, is as important as the true altitude of a flight. Self-imposed stressors, such as tobacco and alcohol, increase the physiological altitude.

2-73. **Smoking.** The hemoglobin molecules of RBCs have a 200- to 300-times greater affinity for carbon monoxide than for oxygen. Cigarette smoking significantly increases the amount of CO carried by the hemoglobin of RBCs; thus, it reduces the capacity of the blood to combine with oxygen. Smoking 3 cigarettes in rapid succession or 20 to 30 cigarettes within 24 hours before a flight may saturate from 8 to 10 percent of the hemoglobin in the blood. The physiological effects of this condition include—

- The loss of about 20 percent of the smoker's night vision at sea level.
- A physiological altitude of 5,000 feet at sea level, as depicted in Figure 2-15.

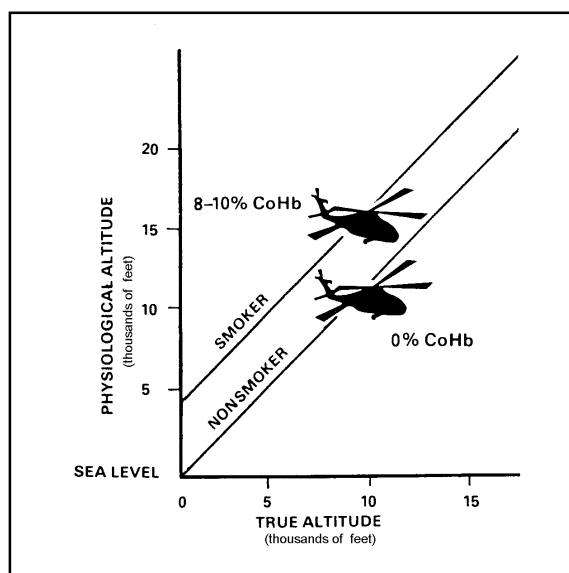


Figure 2-15. Adverse Effects of Altitude on Smokers

2-74. **Alcohol.** Alcohol creates histotoxic hypoxia. For example, an individual who has consumed 1 ounce of alcohol may have a physiological altitude of 2,000 feet.

Individual Factors

2-75. Metabolic rate, diet, nutrition, and emotions greatly influence an individual's susceptibility to hypoxia. These and other individual factors must be considered in determining susceptibility.

Ascent Rate

2-76. Rapid ascent rates affect the individual's susceptibility to hypoxia. High altitudes can be reached before the crew member notices serious symptoms.

Exposure Duration

2-77. The effects of exposure to altitude relate directly to an individual's length of exposure. Usually, the longer the exposure, the more detrimental the effects. However, the higher the altitude, the shorter the exposure time required before symptoms of hypoxia occur.

Ambient Temperature

2-78. Extremes in temperature usually increase the metabolic rate of the body. A temperature change increases the individual's oxygen requirements while decreasing the tolerance of the body to hypoxia. With these conditions, hypoxia may develop at lower altitudes than usual.

Physical Activity

2-79. When physical activity increases, the body demands a greater amount of oxygen. This increased oxygen demand causes a more rapid onset of hypoxia.

Physical Fitness

2-80. An individual who is physically conditioned will normally have a higher tolerance to altitude problems than one who is not. Physical fitness raises an individual's tolerance ceiling.

EFFECTS OF HYPOXIA

2-81. In aviation, the most important effects of hypoxia are those related, either directly or indirectly, to the nervous system. Nerve tissue has a heavy requirement for oxygen. Brain tissue is one of the first areas affected by an oxygen deficiency. A prolonged or severe lack of oxygen destroys brain cells. Hypoxia demonstrations in an altitude chamber do not produce any known brain damage because the severity and duration of the hypoxia are minimized.

2-82. The expected performance time is from the interruption of the oxygen supply until the crew member loses the ability to take corrective action. Table 2-5 shows that the EPT varies with the altitude at which the individual is flying. An aircrew flying in a pressurized aircraft that loses cabin

pressurization, as in rapid decompression, has only one-half of the EPT shown in Table 2-5.

Table 2-5. Relationship Between Expected Performance Time and Altitude

Altitude (feet)	Expected Performance Time
>50,000	9–12 seconds
43,000	9–12 seconds
35,000	30–60 seconds
25,000	4–6 minutes
22,000	8–10 minutes
18,000	20–30 minutes

STAGES OF HYPOXIC HYPOXIA

2-83. There are four stages of hypoxic hypoxia: indifferent, compensatory, disturbance, and critical. Table 2-6 shows that the stages vary according to the altitude and the severity of symptoms.

INDIFFERENT STAGE

2-84. Mild hypoxia in this stage causes night vision to deteriorate at about 4,000 feet. Aircrew members who fly above 4,000 feet at night should be aware that visual acuity decreases significantly in this stage because of both the dark conditions and the developing mild hypoxia.

Table 2-6. Stages of Hypoxia

Stages	Indifferent Stage (98%–90% O₂ saturation)	Compensatory Stage (89%–80% O₂ saturation)	Disturbance Stage (79%–70% O₂ saturation)	Critical Stage (69%–60% O₂ saturation)
Altitude (thousands of feet)	0–10	10–15	15–20	20–25
Symptoms	Decrease in night vision	Drowsiness Poor judgment Impaired coordination Impaired efficiency	Impaired flight control Impaired handwriting Impaired speech Decreased coordination Impaired vision Decreased sensation to pain Impaired intellectual function Decreased memory Impaired judgment	Circulatory failure CNS failure Convulsions Cardiovascular collapse Death

COMPENSATORY STAGE

2-85. The circulatory system and, to a lesser degree, the respiratory system provide some defense against hypoxia at this stage. The pulse rate, systolic blood pressure, circulation rate, and cardiac output increase. Respiration increases in depth and sometimes in rate. At 12,000 to 15,000 feet, however, the effects of hypoxia on the nervous system become increasingly apparent. After 10 to 15 minutes, impaired efficiency is obvious. Crew members may become drowsy and make frequent errors in judgment. They may also find it difficult to do even simple tasks requiring alertness or moderate muscular coordination. Crew members preoccupied with duties can easily overlook hypoxia at this stage.

DISTURBANCE STAGE

2-86. In this stage, the physiological responses can no longer compensate for the oxygen deficiency. Occasionally, crew members become unconscious from hypoxia without undergoing the subjective symptoms described in Table 2-6. Fatigue, sleepiness, dizziness, headache, breathlessness, and euphoria are the symptoms most often reported. The objective symptoms explained below are also experienced.

Senses

2-87. Peripheral vision and central vision are impaired, and visual acuity is diminished. Weakness and loss of muscular coordination are experienced. The sensations of touch and pain are diminished or lost. Hearing is one of the last senses to be lost.

Mental Processes

2-88. Intellectual impairment is an early sign that often prevents the individual from recognizing disabilities. Thinking is slow, and calculations are unreliable. Short-term memory is poor, and judgment—as well as reaction time—is affected.

Personality Traits

2-89. There may be a display of basic personality traits and emotions much the same as with alcoholic intoxication. Euphoria, aggressiveness, overconfidence, or depression can occur.

Psychomotor Functions

2-90. Muscular coordination is decreased, and delicate or fine muscular movements may be impossible. Stammering and illegible handwriting are typical of hypoxic impairment.

Cyanosis

2-91. When cyanosis occurs, the skin becomes bluish in color. This effect is caused by oxygen molecules failing to attach to hemoglobin molecules.

CRITICAL STAGE

2-92. Within three to five minutes, judgment and coordination usually deteriorate. Subsequently, mental confusion, dizziness, incapacitation, and unconsciousness occur.

PREVENTION OF HYPOXIC HYPOXIA

2-93. An understanding of the causes and types of hypoxia assists in its prevention. Hypoxic (altitude) hypoxia is the type most often encountered in aviation. The other three types (hypemic, stagnant, and histotoxic) may also present danger to aviators.

2-94. Hypoxic hypoxia can be prevented by ensuring that sufficient oxygen is available to maintain an alveolar partial pressure of oxygen (PAO₂) between 60 and 100 mm/Hg. Preventive measures include—

- Limiting the time at altitude.
- Using supplemental oxygen.
- Pressurizing the cabin.

2-95. During night flights above 4,000 feet, crew members should use supplemental oxygen when available. Supplemental oxygen is necessary because of the mild hypoxia and loss of visual acuity that occur.

2-96. The amount, or percentage, of oxygen required to maintain normal oxygen saturation levels varies with altitude. At sea level, a 21 percent concentration of ambient air oxygen is necessary to maintain the normal blood oxygen saturation of 96 to 98 percent. At 20,000 feet, however, a 49 percent concentration of oxygen is required to maintain the same saturation.

2-97. The upper limit of continuous-flow oxygen is reached at about 34,000 feet. Above 34,000 feet, positive pressure is necessary to maintain an adequate oxygen saturation level. The positive pressure, however, cannot exceed 30 mm/Hg because—

- Normal oxygen masks cannot hold positive pressures of more than 25 mm/Hg without leaking.
- Excess pressure may enter the middle ear through the eustachian tubes and cause the eardrum to bulge outward, which is painful.
- Crew members encounter difficulty in exhalation against the pressure, resulting in hyperventilation.

2-98. Pressurization, as found in the C-12 aircraft, can prevent hypoxia. Supplemental oxygen should be available in the aircraft in case of pressurization loss.

2-99. The prevention of hypoxic hypoxia is essential in the aviation environment. There are, however, other causes of hypoxia. Carbon monoxide uptake (hypemic hypoxia), the effects of alcohol (histotoxic hypoxia), and reduced blood flow (stagnant hypoxia) are also hazardous. Avoiding or minimizing self-imposed stressors helps eliminate hypoxic conditions.

TREATMENT OF HYPOXIA

2-100. Individuals who exhibit signs and symptoms of hypoxia must be treated immediately. Treatment consists of giving the individual 100 percent oxygen. If oxygen is not available, descent to an altitude below 10,000 feet is mandatory. When symptoms persist, the type and cause of the hypoxia must be determined and treatment administered accordingly.

SECTION V – HYPERVENTILATION

CHARACTERISTICS OF HYPERVENTILATION

2-101. Hyperventilation is the excessive rate and depth of respiration leading to abnormal loss of carbon dioxide from the blood. This condition occurs more often among aviators than is generally recognized. It seldom incapacitates completely, but it causes disturbing symptoms that can alarm the uninformed aviator. In such cases, an increased breathing rate and anxiety then further aggravate the problem.

CAUSES OF HYPERVENTILATION

2-102. The human body reacts automatically under conditions of stress and anxiety whether the problem is real or imaginary. Often, a marked increase in breathing rate occurs. This increase leads to a significant decrease in the carbon-dioxide content of the body as well as a change in the acid-base balance. Among the factors that can initiate this cycle are emotions, pressure breathing, and hypoxia.

EMOTIONS

2-103. When fear, anxiety, or stress alters the normal breathing pattern, the individual may attempt to consciously control breathing. The respiration rate is then likely to increase without an elevation in CO₂ production, and hyperventilation occurs.

PRESSURE BREATHING

2-104. Positive-pressure breathing is used to prevent hypoxia at altitude. It reverses the normal respiratory cycle of inhalation and exhalation.

Inhalation

2-105. Under positive-pressure conditions, the aviator is not actively involved in inhalation as in the normal respiratory cycle. The aviator does not inhale oxygen into the lungs; instead, oxygen is forced into the lungs under positive pressure.

Exhalation

2-106. Under positive-pressure conditions, the aviator is forced to breathe out against the pressure. The force that the individual must exert in exhaling results in an increased rate and depth of breathing. At this point, too much CO₂ is lost and alkalosis, or increased pH, occurs. Pauses between exhaling

and inhaling can reverse this condition and maintain a near-normal level of CO₂ during pressure breathing.

HYPOXIA

2-107. With the onset of hypoxia and the resultant lower oxygen-saturation level of the blood, the respiratory center triggers an increase in the breathing rate to gain more oxygen. This rapid breathing, which is beneficial for oxygen uptake, causes excessive loss of carbon dioxide when continued too long.

SIGNS AND SYMPTOMS OF HYPERVENTILATION

2-108. The excessive loss of CO₂ and the chemical imbalance that occur during hyperventilation produce signs and symptoms. These include—

- Dizziness.
- Muscle spasms.
- Unconsciousness.
- Visual impairment.
- Tingling sensations.
- Hot and cold sensations.

The signs and symptoms of hyperventilation and hypoxia are similar, making them difficult to differentiate. The indications given below help to distinguish between the two.

Hyperventilation

2-109. Hyperventilation results in nerve and muscle irritability and muscle spasms. Symptoms appear gradually.

Fainting

2-110. Fainting produces loose muscles but no muscle spasms. Symptoms appear rapidly.

TREATMENT OF HYPERVENTILATION

2-111. The most effective method of treatment is voluntary reduction in the affected individual's rate of respiration. However, an extremely apprehensive person may not respond to directions to breathe more slowly.

2-112. Although it is difficult, an individual affected by the symptoms of hyperventilation should try to control the respiration rate; the normal rate is 12 to 16 breaths per minute. To treat hyperventilation, the aviator should control breathing and go to 100 percent oxygen. If symptoms continue and conscious control of respiration is not possible, the individual should talk or sing. It is physiologically impossible to talk and hyperventilate at the same time. Talking or singing will elevate the CO₂ level and help regulate breathing.

2-113. When hypoxia and hyperventilation occur concurrently, a decrease in the respiratory rate and the intake of 100 percent O₂ will correct the

condition. If hypoxia is severe, the aviator must return to ground level before becoming incapacitated.

SECTION VI – PRESSURE-CHANGE EFFECTS

DYSBARISM

2-114. The human body can withstand enormous changes in barometric pressure as long as air pressure in the body cavities equals ambient air pressure. Difficulty occurs when the expanding gas cannot escape so that ambient and body pressures can equalize. The discussion in this section applies to nonpressurized flight and direct exposure of aircrews to potentially harmful altitudes.

2-115. Dysbarism refers to the various manifestations of gas expansion induced by decreased barometric pressure. These manifestations can be just as dangerous, if not more so, than hypoxia or hyperventilation. The direct effects of decreased barometric pressure can be divided into two groups: trapped-gas disorders and evolved-gas disorders.

TRAPPED-GAS DISORDERS

2-116. During ascent, the free gas normally present in various body cavities expands. If the escape of the expanded volume is impeded, pressure builds up within the cavity and pain is experienced. The expansion of trapped gases accounts for abdominal pain, ear pain, sinus pain, or toothache.

BOYLE'S LAW

2-117. Trapped-gas problems are explained by the physical laws governing the behavior of gases under conditions of changing pressure. Boyle's Law (Figure 2-16) states that the volume of a gas is inversely proportional to the pressure exerted upon it. Differences in gas expansion are found under conditions of dry gas and wet gas.

Dry-Gas Conditions

2-118. Under dry-gas conditions, the atmosphere is not saturated with moisture. Under conditions of constant temperature and increased altitude, the volume of a gas expands as the pressure decreases.

Wet-Gas Conditions

2-119. Gases within the body are saturated with water vapor. Under constant temperature and at the same altitude and barometric pressure, the volume of wet gas is greater than the volume of dry gas.

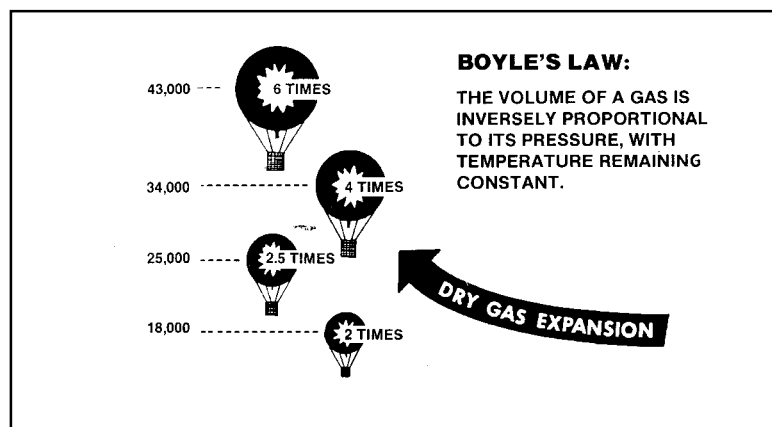


Figure 2-16. Boyle's Law

TRAPPED-GAS DISORDERS OF THE GASTROINTESTINAL TRACT

2-120. With a rapid decrease in atmospheric pressure, aircrews frequently experience discomfort from gas expansion within the digestive tract. At low or intermediate altitudes, the symptom is not serious in most individuals. Above 25,000 feet, however, enough distension may occur to produce severe pain. Figure 2-17 shows the dramatic expansion of trapped gas as altitude increases.

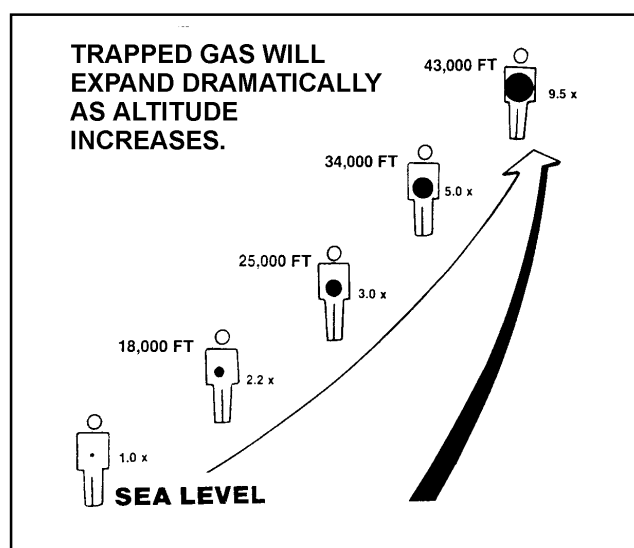


Figure 2-17. Trapped-Gas Expansion in the Gastrointestinal Tract at Increased Altitudes

Cause

2-121. The stomach and the small and large intestines normally contain a variable amount of gas at a pressure roughly equal to the surrounding atmospheric pressure. The stomach and large intestine contain considerably more gas than does the small intestine. The chief sources of this gas are swallowed air and, to a lesser degree, gas formed as a result of digestive processes, fermentation, bacterial decomposition, and decomposition of food

undergoing digestion. The gases normally present in the gastrointestinal tract are oxygen, carbon dioxide, nitrogen, hydrogen, methane, and hydrogen sulfide. The proportions vary, but the highest percentage of the gas mixture is always nitrogen.

Effects

2-122. The absolute volume or location of the gas may cause gastrointestinal pain at high altitude. Sensitivity or irritability of the intestine, however, is a more important cause of gastrointestinal pain. Therefore, an individual's response to high altitude varies, depending on such factors as fatigue, apprehension, emotion, and general physical condition. Gas pains of even moderate severity may produce marked lowering of blood pressure and loss of consciousness if distension is not relieved. For this reason, any individual experiencing gas pains at altitude should be watched for pallor or other signs of fainting. If these signs are noted, an immediate descent should be made.

Prevention

2-123. Aircrews should maintain good eating habits to prevent gas pains at high altitudes. Some foods that commonly produce gas are onions, cabbages, raw apples, radishes, dried beans, cucumbers, and melons. Crew members who participate regularly in high-altitude flights should avoid foods that disagree with them. Chewing the food well is also important. When people drink liquids or chew gum, they unavoidably swallow air. Therefore, crew members should avoid drinking large quantities of liquids, particularly carbonated beverages, before high-altitude missions and chewing gum during ascent. Eating irregularly, hastily, or while working makes individuals more susceptible to gas pains. Crew members who fly frequent, long, and difficult high-altitude missions should be given special consideration in diet and in the environment in which they eat. They should watch their diet, chew food well, and keep regular bowel habits.

Relief

2-124. If trapped-gas problems exist in the gastrointestinal tract at high altitude, belching or passing flatus will ordinarily relieve the gas pains. If pain persists, descent to a lower altitude is necessary.

TRAPPED-GAS DISORDERS OF THE EARS

2-125. The ear is not only an organ of hearing but also one of regulating equilibrium. When ascending to altitude, aircrew members often experience physiological discomfort during changes in atmospheric pressure. As barometric pressure decreases during ascent, the expanding air in the middle ear (Figure 2-18) is intermittently released through the eustachian tube (slender tube between the middle ear and the pharynx) into the nasal passages. As the inside pressure increases, the eardrum bulges until an excess pressure of about 12 to 15 mm/Hg is reached. At this time, the air trapped in the middle ear is forced out of the middle ear and the eardrum resumes its normal position. Just before the air escapes into the eustachian tube, there is a sensation of fullness in the ear. As the pressure is released, there is often a click or pop.

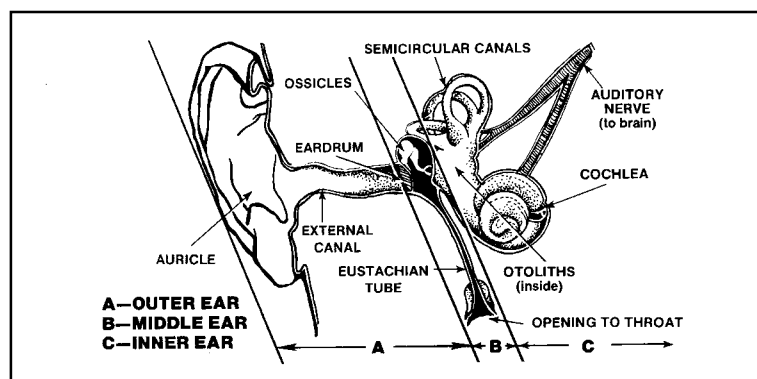


Figure 2-18. Anatomy of the Ear

Cause

2-126. During flight. During descent, the change in pressure within the ear may not occur automatically. Equalizing the pressure in the middle ear with that of the outside air may be difficult. The eustachian tube allows air to pass outward easily but resists passage in the opposite direction. With the increase in barometric pressure during descent, the pressure of the external air is higher than the pressure in the middle ear and the eardrum is pushed in (Figure 2-19). If the pressure differential increases appreciably, it may be impossible to open the eustachian tube. This painful condition could cause the eardrum to rupture because the eustachian tube cannot equalize the pressure. When the ears cannot be cleared, marked pain ensues. If the pain increases with further descent, ascending to a level at which the pressure can be equalized provides the only relief. Then a slow descent is recommended. Descending rapidly from a level of 30,000 to 20,000 feet will often cause no discomfort; a rapid descent from 15,000 to 5,000 feet, however, will cause great distress. The change in barometric pressure is much greater in the latter situation. For this reason, special care is necessary during rapid descents at low altitudes.

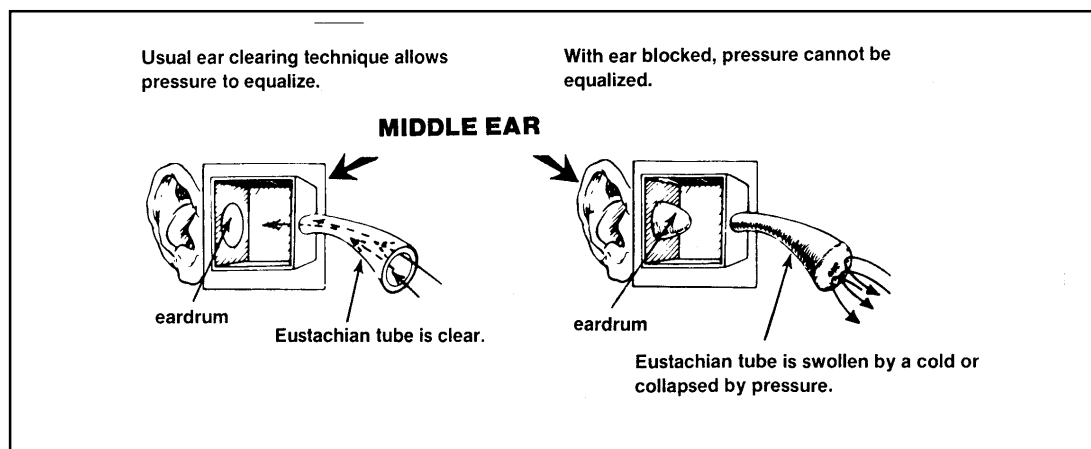


Figure 2-19. Pressure Effect on the Middle Ear During Descent

2-127. **After Flight.** Crew members who have breathed pure oxygen during an entire flight sometimes develop delayed ear block several hours after landing, although their ears were cleared adequately during descent. Delayed ear blocks are caused by saturation of the middle ear with oxygen. After crew members return to breathing ambient air, the tissue gradually reabsorbs the oxygen present in the middle ear. When a sufficient amount is absorbed, the pressure in the ear becomes less than that on the outside of the eardrum. Ear pain may awaken crew members after they have gone to sleep, or they may notice it when they awake the following morning. Usually this condition is mild and can be relieved by performing the Valsalva maneuver explained in paragraph 2-130 below.

Complications From Preexisting Physical Conditions

2-128. **Respiratory Infections.** Crew members often complain of discomfort in the ears caused by inability to ventilate the middle ear adequately. Such inability occurs most frequently when the eustachian tube or its opening is swollen shut as the result of inflammation or infection coincidental with a head cold, sore throat, infection of the middle ear, sinusitis, or tonsillitis. In such cases, forceful opening of the tube may cause a disease-carrying infection to enter the middle ear along with the air. Therefore, crew members who have colds and sore throats should not fly. If flight is essential, slow descents will equalize pressure more easily.

2-129. **Temporal Bone and Jaw Problems.** Although upper respiratory infections are the main causes of narrowing of the eustachian tube, there are other causes. Crew members with malposition of the temporomandibular joint (temporal bone and jaw) may have ear pain and difficulty both in ventilating the middle ear and in hearing. In these cases, movement of the jaw (or yawning) relaxes surrounding soft tissues and clears the opening of the eustachian tube.

Prevention and Treatment

2-130. **During Flight.** Normally, crew members can equalize pressure during descent by swallowing or yawning or by tensing the muscles of the throat. If these methods do not work, they can perform the Valsalva maneuver. To do this, they close the mouth, pinch the nose shut, and blow sharply. This maneuver forces air through the previously closed eustachian tube in the cavity of the middle ear; pressure will equalize. With repeated practice in rapidly clearing the ears, crew members can more easily tolerate increased rates of descent.

Note: To avoid overpressurization of the middle ear, crew members should never attempt a Valsalva maneuver during ascent.

2-131. **After Flight.** If middle-ear and ambient pressures have not equalized after landing and the condition persists, aviation personnel should consult a flight surgeon because barotitis media can occur. This is an acute or chronic traumatic inflammation of the middle ear caused by a difference of pressure on opposite sides of the eardrum. It is characterized by congestion, inflammation, discomfort, and pain in the middle ear and may be followed by temporarily or permanently impaired hearing, usually the former.

TRAPPED-GAS DISORDERS OF THE SINUSES

2-132. Like the middle ear, sinuses can also trap gas during flight. The sinuses (Figure 2-20) are air-filled, relatively rigid, bony cavities lined with mucous membranes. They connect with the nose by means of one or more small openings. The two frontal sinuses are within the bones of the forehead; the two maxillary sinuses are within the cheekbones; and the two ethmoid sinuses are within the bones of the nose.

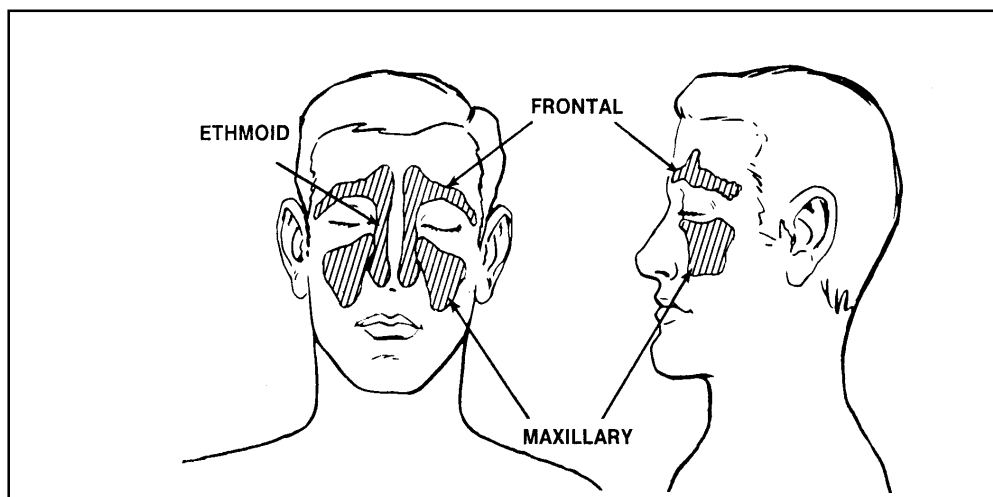


Figure 2-20. Sinus Cavities

Cause

2-133. If the openings into the sinuses are normal, air passes into and out of these cavities without difficulty and pressure equalizes during ascent or descent. Swelling of the mucous membrane lining, caused by an infection or allergic condition, may obstruct the sinus openings. Viscous secretions that coat tissue may also cover the openings. These conditions may make it impossible to equalize the pressure. Change of altitude produces a pressure differential between the inside and the outside of the cavity, sometimes causing severe pain. Unlike the ears, ascent and descent almost equally affect the sinuses. If the frontal sinuses are involved, the pain extends over the forehead above the bridge of the nose. If the maxillary sinuses are affected, the pain is on either side of the nose in the region of the cheekbones. Maxillary sinusitis may produce pain in the teeth of the upper jaw; the pain may be mistaken for toothache.

Prevention

2-134. As with middle-ear problems, sinus problems are usually preventable. Aircrew members should avoid flying when they have a cold or congestion. During descent, they can perform the Valsalva maneuver often. The opening to a sinus cavity is quite small, compared to the Eustachian tube; unless the pressure is equalized, extreme pain will result. If crew members notice any pain in a sinus on ascent, they should avoid any further increase in altitude.

Treatment

2-135. If a sinus block occurs during descent, aircrews should avoid further descent. They should attempt a forceful Valsalva maneuver. If this maneuver does not clear the sinuses, they should ascend to a higher altitude. This ascent will ventilate the sinuses. They can also perform the normal Valsalva maneuver during slow descent to the ground. If the aircraft is equipped with pressure-breathing equipment, they can use oxygen, under positive pressure, to ventilate the sinuses. If the pressure does not equalize after landing, crew members should consult the flight surgeon.

TRAPPED-GAS DISORDERS OF THE TEETH

2-136. Changes in barometric pressure cause toothache, or barodontalgia. This is a significant but correctable indisposition. The toothache usually results from an existing dental problem. The onset of toothache generally occurs from 5,000 to 15,000 feet. In a given individual, the altitude at which the pain occurs shows a remarkable constancy. The pain may or may not become more severe as altitude increases. Descent almost invariably brings relief; the toothache often disappears at the same altitude at which it first occurred.

EVOLVED-GAS DISORDERS

2-137. Evolved-gas disorders occur in flight when atmospheric pressure is reduced as a result of an increase in altitude. Gases dissolved in body fluids at sea-level pressure are released from solution and enter the gaseous state as bubbles when ambient pressure is lowered (Henry's Law). This will cause varied skin and muscle symptoms, which are sometimes followed by neurological symptoms. Evolved-gas disorders are also known as decompression sickness.

HENRY'S LAW

2-138. The amount of gas dissolved in a solution is directly proportional to the pressure of the gas over the solution. Henry's Law is similar to the example of gases being held under pressure in a soda bottle (Figure 2-21). When the cap is removed, the liquid inside is subject to a pressure less than that required to hold the gases in solution; therefore, gases escape in the form of bubbles. Nitrogen in the blood is affected by pressure changed in this same manner.

2-139. Inert gases in body tissues (principally nitrogen) are in equilibrium with the partial pressures of the same gases in the atmosphere. When barometric pressure decreases, the partial pressures of atmospheric gases decrease proportionally. This decrease in pressure leaves the tissues temporarily supersaturated. Responding to the supersaturation, the body attempts to establish a new equilibrium by transporting the excess gas volume in the venous blood to the lungs.

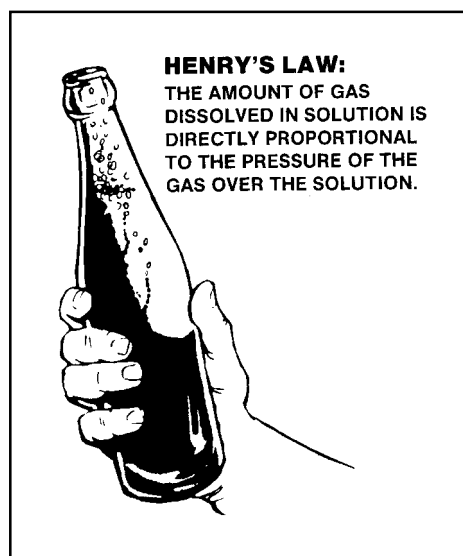


Figure 2-21. Henry's Law

CAUSE

2-140. The cause of the various symptoms of decompression sickness is not fully understood. This sickness can be attributed to the nitrogen saturation of the body. This is related, in turn, to the inefficient removal and transport of the expanded nitrogen gas volume from the tissues to the lungs. Diffusion to the outside atmosphere would normally take place here.

2-141. Tissues and fluid of the body contain from 1 to 1.5 liters of dissolved nitrogen, depending on the pressure of nitrogen in the surrounding air. As altitude increases, the partial pressure of atmospheric nitrogen decreases and nitrogen leaves the body to reestablish equilibrium. If the change is rapid, recovery of equilibrium lags, leaving the body supersaturated. The excess nitrogen diffuses into the capillaries in solution and is carried by the venous blood for elimination. With rapid ascent to altitudes of 30,000 feet or more, nitrogen tends to form bubbles in the tissues and in the blood. In addition to nitrogen, the bubbles contain small quantities of carbon dioxide, oxygen, and water vapor. Additionally, fat dissolves five or six times more nitrogen than blood. Thus, tissues having the highest fat content are more likely to form bubbles.

INFLUENTIAL FACTORS

2-142. Evolved-gas disorders do not happen to everyone who flies. The following factors tend to increase the chance of evolved-gas problems.

Rate of Ascent, Level of Altitude, and Duration of Exposure

2-143. In general, the more rapid the ascent, the greater the chance that evolved-gas disorders will occur; the body does not have time to adapt to the pressure changes. At altitudes below 25,000 feet, symptoms are less likely to occur; above 25,000 feet, they are more likely to occur. The longer the exposure, especially above 20,000 feet, the more likely that evolved-gas disorders will occur.

Age and Body Fat

2-144. An increase in the incidence of decompression sickness occurs with increasing age, with a three-fold increase in incidence between the 19- to 25-year old and the 40- to 45-year old age groups. The reason for this increase is not understood but may result from the changes in circulation caused by aging. No scientific validation exists to support any link between obesity and the incidence of decompression sickness.

Physical Activity

2-145. Physical exertion during flight significantly lowers the altitude at which evolved-gas disorders occur. Exercise also shortens the amount of time that normally passes before symptoms occur.

Frequency of Exposure

2-146. **Types of Evolved-Gas Disorders.** Frequency of exposure tends to increase the risk of evolved-gas disorders. The more often that individuals are exposed to altitudes above 18,000 feet (without pressurization), the more that they are predisposed to evolved-gas disorders.

2-147. **Bends.** At the onset of bends, pain in the joints and related tissues may be mild. The pain, however, can become deep, gnawing, penetrating, and eventually, intolerable. The pain tends to be progressive and becomes worse if ascent is continued. Severe pain can cause loss of muscular power of the extremity involved and, if allowed to continue, may result in bodily collapse. The pain sensation may diffuse from the joint over the entire area of the arm or leg. In some instances, it arises initially in muscle or bone rather than in a joint. The larger joints, such as the knee or shoulder, are most frequently affected. The hands, wrists, and ankles are also commonly involved. In successive exposures, pain tends to recur in the same location. It may also occur in several joints at the same time and worsens with movement and weight bearing. Coarse tremors of the fingers are often noted when the bends occur in joints of the arm.

2-148. **Chokes.** Symptoms occurring in the thorax are probably caused, in part, by innumerable small bubbles that block the smaller pulmonary vessels. At first, a burning sensation is noted under the sternum. As the condition progresses, the pain becomes stabbing and inhalation is markedly deeper. The sensation in the chest is similar to one that an individual experiences after completing a 100-yard dash. Short breaths are necessary to avoid distress. There is an almost uncontrollable desire to cough, but the cough is ineffective and nonproductive. Finally, there is a sensation of suffocation; breathing becomes more shallow, and the skin turns bluish. When symptoms of chokes occur, immediate descent is imperative. If allowed to progress, the condition leads to collapse and unconsciousness. Fatigue, weakness, and soreness in the chest may persist for several hours after the aircraft lands.

2-149. **Paresthesia.** Tingling, itching, cold, and warm sensations are believed to be caused by bubbles formed either locally or in the CNS where they involve nerve tracts leading to the affected areas in the skin. Cold and warm sensations of the eyes and eyelids, as well as occasional itching and gritty sensations, are sometimes noted. A mottled red rash may appear on the

skin. More rarely, a welt may appear, accompanied by a burning sensation. Bubbles may develop just under the skin, causing localized swelling. Where there is excess fat beneath the skin in the affected region, soreness accompanied by an abnormal accumulation of fluid may be present for one or two days.

2-150. Central Nervous System Disorders. In rare cases when aircrews are exposed to high altitude, symptoms may indicate that the brain or the spinal cord is affected by nitrogen-bubble formation. The most common symptoms are visual disturbances such as the perception of lights as flashing or flickering when they are actually steady. Other symptoms may be a dull-to-severe headache, partial paralysis, the inability to hear or speak, and the loss of orientation. Paresthesia or one-sided numbness and tingling may also occur. Hypoxia and hyperventilation may cause similar numbness and tingling; however, these are bilateral—they occur in both arms, legs, or sides. CNS disorders are considered a medical emergency; if they occur at high altitude, immediate descent and hospitalization are indicated.

PREVENTION

2-151. In high-altitude flight and during hypobaric-chamber operations, aircrews can be protected against decompression sickness. Protective measures include—

- Denitrogenation.
- Cabin pressurization.
- Limitation of time at high altitude.
- Aircrew restrictions.

Denitrogenation

2-152. Aircrews are required to breathe 100 percent oxygen for 30 minutes before takeoff for flights above 18,000 feet. Denitrogenation rids the body of excess nitrogen. This dumping of nitrogen from the body takes place because no nitrogen is coming in via the oxygen mask under 100 percent oxygen. The amount of nitrogen lost depends strictly on time. Within the first 30 minutes of denitrogenation (Figure 2-22), the body loses about 30 percent of its nitrogen.

Cabin Pressurization

2-153. The pressurized aircraft cabin is usually maintained at a pressure equivalent to an altitude of 10,000 feet or below. This pressure lessens the possibility of nitrogen-bubble formation.

Limitation of Time at High Altitude

2-154. The longer one stays at high altitude, the more nitrogen bubbles will form. Extended, unpressurized flight above 20,000 feet should be minimized.

Aircrew Restrictions

2-155. AR 40-8 restricts crew members from flying for 24 hours after scuba diving. During scuba diving, excessive nitrogen uptake by the body occurs

while using compressed air. Flying at 8,000 feet within 24 hours after scuba diving at 30 feet subjects an individual to the same factors that a nondiver faces when flying unpressurized at 40,000 feet: nitrogen bubbles form.

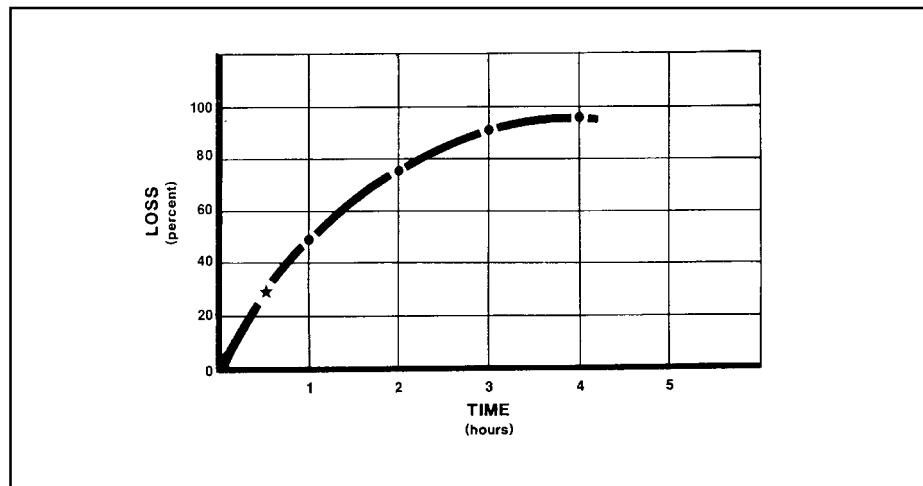


Figure 2-22. Nitrogen Elimination

TREATMENT

2-156. When symptoms and signs of evolved-gas disorders appear, aircrews should take the following corrective actions:

- Descend to ground level immediately.
- Place the affected individual on 100 percent oxygen to eliminate any additional nitrogen uptake and to remove excessive nitrogen from the system.
- Immobilize the affected area to prevent further movement of nitrogen bubbles in the circulatory system.
- Report to the flight surgeon or to the best medical assistance available.
- Undergo compression therapy in a hyperbaric chamber if symptoms persist and when prescribed by a flight surgeon.

DELAYED ONSET OF DECOMPRESSION SICKNESS

2-157. The onset of decompression sickness can occur as long as 48 hours after exposure to altitudes above 18,000 feet. This delayed onset may occur even if no signs/symptoms were evident during the flight.